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ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH.

Project Prodigal

Assessment of the Feasibility Studies Submitted to Specification No. FVPDE.5258

by

Aerodynamics Department and I.A.P. Department, R.A.E.

1. Introduction

Project Prodigal covers feasibility studies for an Army scout car having an airborne capability, which may be limited to jumps over obstacles including rivers, or may extend to steady flight for several miles. It is intended that this capability should be used only when the vehicle can no longer proceed as a land vehicle with good cross country performance, because it is presumed that the ground vehicle could penetrate further without being detected by the enemy.

As a result of the submissions of the seven different firms (of which two have offered two separate solutions) it can now be seen that the problem becomes the simultaneous provision of (1) a cross-country land vehicle with a "payload" (including all its airborne machinery and fuel) of some 50% of its gross weight, and (2) an easily controlled VTOL aircraft of limited range and speed but capable of 50 take-offs with a "payload" (including all its ground-borne propulsion system and fuel and its wheels and suspension) of some 40% of its gross weight. These are to be achieved within a vehicle some 16 ft. long and 8 ft. wide, and are both considerable problems in design.

On the first aspect we can say little, except that if the gross weight and size are not to become too great, there must be considerable savings in the weight of the structure of the vehicle compared with present Army practice. Such savings might come from the acceptance of a slightly reduced cross-country performance, from the abandonment of armour and from aircraft methods of construction. The problem then is to retain military vehicle standards of ruggedness and reliability.

On the second aspect, of the VTOL machine, we shall now examine the various proposals from the points of view of feasibility and practical worth.

2. Solutions of the Problem

2.1 General

In general, each design is a solution of the problem of providing at least the capability of achieving 50 jumps over a 10 ft. high x 30 ft. wide obstacle. In each case it is achieved straightforwardly by providing a static thrust exceeding the gross weight of the vehicle*. In all but one case, the cross-country performance should be adequate, and the required military load can be carried. The exception is the private venture of Bristol Siddeley which is a light machine with limited cross-country performance and only half the required payload; the payload could however be increased at some cost in performance.

/The

* One other firm, English Electric, is thinking round the possibility of using favourable ground effect, so that a thrust of slightly less than the weight could be used. Jumping out of the ground effect allows a maximum height greater than the equilibrium height in ground effect. No formal proposals have been submitted.

The achievement of the static thrust is tackled in different ways, but in general three main classes of vehicle can be distinguished, dependent upon the airborne time for any one sortie. These are

(i) Jumps, limited in height (say 20 ft.) and range (less than 100 ft.).

(ii) Short flights, including jumps and flights of 1000 ft. range and over (up to 50,000 ft. total).

(iii) Extended flights, of considerably more than 10 miles.

Taking these classes in the reverse order, the long-range group seems closer to the present helicopter solution, and it is felt that these machines (the Westland helicopter and the Handley Page folding-wing machine) are not really within the spirit of the specification.

In the middle group are four central-exit fan machines and one four fan machine. Boulton Paul, Shorts and Handley Page offer ducted fan-engine schemes, while Bristol Siddeley gear three shaft turbines to a central fan. Vickers offer a machine with two shaft turbines geared to four fans, one at each corner. The Bristol machine has a considerably extended flight capability and can fly at 70 - 80 m.p.h. for one hour, so to some extent it could be classified in the previous group. However, with its limited cross-country ability, it may be required to fly more frequently than the other machines, and it has been included in the short range vehicle group.

In the class of "jump" machines are the limited-flight stored energy machines, which use their road engines to store kinetic energy (Westlands) or high pressure air for release through a turbine (Follands). Also in this group will be the English Electric machine that is intended to jump out of ground effect.

Descriptions of the various machines follow. "Payload" here comprises the crew of two, military load including radio, and ground propulsion fuel for 200 miles range.

2.2 Westland No.1 (Helicopter)

This machine is a straightforward grafting of the mechanical parts of a P541 Wasp helicopter onto a vehicle of the Champ type. The tail rotor mounting structure folds up and over to shorten the vehicle on the ground and to provide stowage for the folded main 4-blade rotor. Rotor diameter is 32 ft. 3 in.

The vehicle itself is intended to be similar to the Champ or Land Rover; in fact, weight saving in the structure has been rejected, though some light alloy panelling would be used. The suspension system is basically that of the Champ with long stroke oleos for the landing case. The road engine is a water cooled Coventry Climax V8 of 100 b.h.p.

The flight engine is a Blackburn A129 Nimbus or D.H. Gnome of 1000 s.h.p. It is to be spun continuously by an electric motor while the vehicle is moving, to prevent brinelling of the bearings. The rotors are similar to those of the Wasp, but the control system is different, exchanging some manoeuvrability for improved stability and ease of flying. It will, hoever, be of normal helicopter type as regards pilot's controls.

Conversion for flight involves unfolding the rotor blades and the tail assembly, after first hydraulically unlocking the pins by a handpump in the cockpit. Time for folding or unfolding is expected to be $1\frac{1}{2}$ - 2 minutes.

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The all-up weight of the machine is 7000 lb., including a payload of 1140 lb. and flight fuel of 550 lb. This gives about 50 minutes flight time with a speed that could exceed 120 m.p.h., i.e. about 100 miles range.

Comment

The approach is very nearly conventional helicopter, with somewhat higher disc loading than usual (8.6 lb./ft.^{2} compared with, say, S.57 at 7.5 lb./ft.^{2}).

Because the emphasis is on existing equipment and technology, there is every reason to believe that this machine would fly successfully and that development time would not be long.

However, the unfolding time required, vulnerability of the blades and rotor head, and the large size of the unfolded machine would seem to miss the intentions of the specification.

2.3 Handley Page 120B (Folding Wings)

The machine consists of a land vehicle fitted with small folding wings of 27 ft. span and a folding tail unit, powered by a fan lift engine of 10,000 lb., with central outlet through a deflecting nozzle and an additional engine of 3200 lb. thrust which can be used for lift or propulsion by means of swivelling nozzles at the sides. Another proposal (Mk. 2) replaces these two engines by one BS.53/5 engine with two cold and two hot exits at the sides of the machine, these having nozzles which can be swivelled between vertical and aft.

The structure is of light alloy or moulded glass fibre panels on a light alloy frame forming deep longitudinal beams. Suspension is similar to Ferret, but gives a long stroke (12 in.) for landing. The engine is a water cooled Coventry Climax FWBB-6 derated to 100 b.h.p.

Vertical take-off, and jumps, are achieved using the fan-lift engine and the deflected jet from the smaller fan engine. The tail unit is extended. Control is then from four puff pipes, at front and rear and on extending arms at each side. Limited authority rate stabilisation in pitch and roll is incorporated, giving synthetic damping. The pilots controls are aircraft type but ailerons and rudders are interconnected to ease piloting.

On the Mk.I machine (central exit) there is a possibility of unfavourable ground effect to the extent of 20 - 30% of thrust. For this reason, take-off is assisted by 3 hydraulic jacks with 18 in. stroke which, giving an initial thrust of 4000 lb., counteract the effect. The Mk. 2 version, with four separate exits, is likely to have zero or positive ground effect, and this complication is unnecessary.

For wingborne flight, the conversion is made hydraulically. No conversion time is stated but in practice the mechanical operation would be quick but checks might be lengthy. It is suggested that the machine would take off with wings folded and then extend the wings when airborne. Transition takes place over a speed range of some 120 m.p.h. (this is the stalling speed); the lift engine then switched off. Cruising speed is 200 m.p.h.

The all-up weight is 9200* including 1200 lb. payload and airborne fuel load of 1700 lb. Provision is made for some light armour. The hopping range is 44 hops of 1000 ft. The free flight range is about 200 miles in one hour or, with a long range tank for ferry purposes, 300 miles, in each case from a vertical take-off.

/Comment

* Mk. 2 weighs 10,000 lb.

Comment

This does not appear to be a well balanced solution to the present problem, which involves 95% of the time as a cross-country vehicle.

The machine is very large (27 ft. long) and heavy, and extremely complicated, having two airborne engines in the Mk.I version, a controllable nozzle, and all the additional folding structure and controls of an aeroplane. The Mk. 2 version is perhaps simpler (but 7 cwt. heavier) with its BS.53 engine, and this engine does exist.

The disc loading is high at about 700 lb./ft.^{2}, with exit velocities of about 700 ft./sec., so ground erosion effects may be severe. On the Mk.I version with its high intake, in spite of the relatively low mass flow associated with high disc loading, the momentum drag effects, particularly the rolling moment due to side gusts, will be very severe and insufficient attention has been paid to this. The further complication, of extending the wings in gusty conditions while hovering, is another considerable difficulty. If wings are extended before take off, the machine is as big as the helicopter submission.

2.4 Vickers (South Marston) (Four Fans)

The machine is lifted and controlled by a variable pitch ducted fan at each corner, the four being driven by a pair of 1400 s.h.p. gas turbines.

The basic vehicle has a semi-monocoque construction, carrying Macpherson type suspension units designed by Dowty to combine cross-country requirements with the landing case. Transmission includes hub reduction gears. The road engine is a water cooled Coventry Climax FWB-6 giving up to 135 b.h.p.

The four ducted fans, of 45 or 51 in. diameter, are shaft driven from two DH Gnome gas turbines developed to give 1350 s.h.p. each, so producing 8320 lb. lift (thrust/weight ratio T/W = 1.03) for short periods. The disc loading of each duct is 145 lb./sq.ft. at the larger diameter. Control is by collective pitch lever and by a control column giving differential lift for pitch and roll. Forward propulsion is by vehicle tilt. Stability has not been considered in great detail.

Gross weight is 8100 lb. for the narrower vehicle (8 ft. 6 in.) with a payload of 1100 lb. and airborne fuel of 870 lb. Claimed performance is 50 hops, either 10 ft. x 30 ft. or 1000 ft. wide, or continuous flight at 50 - 70 m.p.h. for 30 minutes, giving a range of 20 miles with the specified headwinds.

Comment

While the 4-fan layout is attractive from the ground proximity point of view, including erosion, the stability problems of this type of vehicle have already been found very difficult in the U.S., and nothing concrete has been put forward in this proposal.

The driver being well back in the vehicle, visibility may be a problem in both ground and airborne phases.

In this particular proposal, the power available from future developments of the engines is only just sufficient to enable the machine to hover in I.S.A./S.L. conditions. Better performance could result from larger fans, and hence an unacceptably wide vehicle.

It is noted that the ground transmission weights are extremely high in this vehicle.

/2.5

2.5 Bristol Siddeley (Multi-engine, single fan)

This private venture is a concept of lighter weight and lower cross-country performance than the others, but includes considerable excess power to give multi-engined safety. In a lightweight vehicle, three shaft-turbines are geared together (so that any two can provide the required power) to drive mechanically a large contra-rotating fan. It is intended that an extended range should overcome the cross-country limitations.

The vehicle, of steel tube construction with sheet steel reinforcement, all bonded into a glass fibre body, has running gear of Land Rover type. The ground propulsion engine is a Rover gas turbine, easing gear box problems and allowing interchangeability of fuel with the lift engines. Transmission includes hub gears and is considered by the firm to be too heavy; the Lucas Hydrostatic system is to be studied. Suspension is of car type with extra long (15 in.) travel for landing.

The 76 in. diameter contra-rotating fan is driven by three DH Gnome or Blackburn A-129 Nimbus gas turbines, rated at 1000 h.p. Normally only 2000 h.p. is required so the engines are used well below rating; in case of an engine failure, full performance is still available. Forward propulsion is achieved by having the fan assembly tilted by 15°; there are also outlet vanes with a range of $\pm 7\frac{1}{2}^{\circ}$ and the whole machine may be tilted. Stability and control is achieved by jets at the corners of the vehicle, supplied by a separate blower driven from the fan gears; yaw control is by differential operation of the fan outlet vanes. Autostabilisation may be provided; a unified control system with car type controls, with additional freedoms in the steering column, will be used in flight.

The machine has a gross weight of 6000 lb. and carries a payload of 650 lb. and 1200 lb. of flight fuel. This gives a one hour endurance at 70 - 80 m.p.h. and should allow the appropriate number of high and long jumps. The maximum altitude is 10,000 ft.

Comment

With the exception of its cross-country performance and the limited aim of the proposal, this seems an attractive machine.

Particularly good is the low intake, which minimises the momentum drag problems, allied with the provision of control forces within the planform of the vehicle. These forces can be increased by providing a larger compressor utilising some of the built-in excess power to drive it.

The excess power is obviously useful for hot and high take offs and to give safety; on the other hand, one engine could be sacrificed to give the specified military load without loss of performance in I.S.A./S.L. conditions. If the engine were capable of development (e.g. D.H. Gnome rather than Blackburn Nimbus) most of the high altitude performance could be recovered.

The payload deficiency is some 350 lb.; this is about a quarter of the lift fuel, so again the military load could be provided if the endurance were reduced to 45 minutes.

The unified ground and flight control system is attractive.

2.6 Boulton Paul (Fan-lift engine)

The proposal comprises a lightweight structure with a large fan-lift engine in a central duct. The vehicle is intended to have Ferret performance, and includes hydrostatic transmission.

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The light alloy structure consists of deep side frames making up a rectangular planform. The long-travel wishbone and airspring suspension systems are carried by the frame. Ground propulsion is by a water cooled Coventry Climax FWB-4 of 100 b.h.p. driving the wheel-hub hydraulic motors via individual pumps.

The lift engine is a BS.59/12 with 65 in. diameter fan, giving 10,000 lb. static thrust with an exit velocity of 525 ft./sec. (T/W = 1.20). Forward propulsion is by vehicle tilt and yaw control is by vanes in the cold jet. Stability and control is achieved by jets at the corners of the vehicle, fed from the lift engine; the stabilization system is hydro-mechanical, and uses the gyroscopic effects of the engine in its flexible mountings as a rate-sensing device. Driver's controls are the same wheel and column as for ground use (in which column movement alters the gear ratio) together with "rudder" pedals and a lift lever.

The gross weight is 8313 lb., payload is 1150 lb. and flight fuel 2224 lb. With this fuel the vehicle can achieve 43 flights of 1000 ft., or a free flight of about 18 miles at 60 - 70 m.p.h.

A further proposal makes use of an aft fan engine (RB.162) with side intakes, which should usefully reduce the control power requirements. It gives a slightly reduced range, e.g. only 40 hops of 1000 ft.

Comment

This machine has a moderate disc loading for a fan-lift machine. It incorporates an attractive proposal for a rugged mechanical stabilization system, and a novel ground transmission system; both of these are heavy, but their advantages in operation might be considerable. There has been an attempt to unite the ground and flight controls.

The side intake version would be preferred.

Flight fuel weight seems high for the disc loading in comparison with other machines.

2.7 Shorts (Fan-lift engine)

The proposal has a bypass engine fitted into a central duct in a light-weight chassis. Cross-country performance is stressed in the study; conventional transmission and suspension are provided.

The structure is a box surrounding the lifting engine. The crew compartment is designed to protect the crew in case of an engine failure at low altitude. The Porsche 90 b.h.p. aircooled engine drives the wheels through a conventional transmission. Suspension is by leading and trailing arms and oleo-spring units giving a 12 in. travel.

The bypasss lift engine is BS.59/11 giving a static thrust of 9,600 lb. (T/W 1.18) . Propulsion is by tilt; the engine is tilted 5°, and vehicle pitch gives further propulsive thrust. Stability and control is by folding puff pipes extending from the corners of the vehicle, with small yaw nozzles at the forward joints. Stability is by a triplicated electro-hydraulic system (duplex for yaw) similar to that on the SC.1. Pilot's control is a miniature stick.

The gross weight is 7050 lb., payload 1160 lb. and flight fuel 1400 lb. The number of 1000 ft. jumps is limited to 40, while the free flight range is about 20 miles. Maximum speed is 65 m.p.h.

/Comment

Comment

This is a high disc loading machine with associated ground erosion possibilities. It does however take advantage of the small duct to produce a small vehicle.

The stabilisation system is full SC.1 type, already developed and highly sophisticated. The control by miniature stick is difficult for test pilots and so probably not suitable for an Army driver. The whole concept of the control system is at aircraft rather than military vehicle level.

Model tests have made the firm aware of the likelihood of large momentum drag moments, and sufficient control power is available for use with the control system proposed.

2.8 Handley Page Type A (fan-lift engine in central duct or deflected jet engine with side exits)

The proposal is for a machine with the required cross-country performance, with a fan-lift engine in a central duct, blowing through a deflecting nozzle. Alternatively, a Mk.2 version has an existing engine with deflected efflux through side exits.

The structure is of light-alloy or moulded glass fibre panels on a light-alloy frame forming deep longitudinal beams. Suspension is similar to Ferret, but gives a long (15 in.) stroke for landing. The road engine is a water cooled Coventry Climax FWBB-6 of 100 b.h.p.

The lift engine is an RB.162 aft-fan unit of 11,000 static thrust ($T/W = 1.37$) Propulsion is by jet deflection through a swivelling spherical nozzle ($\pm 20^{\circ}$ fore and aft). Additional lift for take off, to counteract adverse ground effect, comes from 3 hydraulic jacks with 18 in. stroke initially giving 4000 lb. thrust in all.

The Mk.2 version uses a BS.53/5, a version of the deflected jet engine with side exits incorporating nozzles that can be swivelled to provide combinations of lift and thrust. Thrust is 15,300 lb. (T/W 1.53), and because of the distribution of exits, ground effect may even be beneficial. Control is achieved by the use of extending jet pipes at the sides of the vehicle and pipes at the nose and tail, the latter pair providing yaw as well as pitch control. The autostabilisation proposed is a 10% limited authority system. Operation is by a separate set of flying controls.

Ejector seats are fitted (weight 300 lb.).

Gross weight is 8000 lb. for the Mk.1 version and 10,000 lb. for the Mk.2 version. Payload is 1200 lb. in each case. Flight fuel is 1700 lb. for the Mk.1 and 2340 lb. for the Mk.2. The performance of the Mk.1 is 48 hops of 1000 ft. or a still air flight range of 44 miles at 127 m.p.h. The Mk.2 can do 60 hops of 1000 ft.; with a tail unit fitted for stability and control reasons it has a range of 80 miles at 200 m.p.h.

Comment

This is a large machine with very high intake in the Mk.1 version and is thus likely to have high momentum drag moments. With 10% limited authority stabilisation, the control force proposed is inadequate. The swivelling nozzle is an extra complication and will involve its own extensive development. The high disc loading will involve severe ground erosion.

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The Mk.2 version is more attractive. While still larger and heavier, the control power problem is much eased by abandonment of the top intake. Ground effect, both erosion and adverse lift effects, will be reduced. Perhaps more important, the engine actually exists, and nozzle development has been successfully pursued.

In both versions, the flying controls are not unified with the ground controls.

In general, one gets the impression that these machines are derived from the winged versions, rather than being optimum fan-lift machines.

2.9 Folland (Jumping vehicle with compressed air energy storage)

This machine has full cross-country performance together with the ability to jump over obstacles of limited height and width; this is achieved by driving a large contra rotating fan, for the necessary ten seconds or so, by turbines fed with heated compressed air. The air compressor is driven by the road engine.

The light alloy structure consists of the duct structure with a cab at one end and engine compartment at the other. The suspension consists of long wishbones with oleo-spring units giving a 12 in. travel. The road engine is Coventry Climax FWB of 94 b.h.p. driving through a conventional transmission.

The lift unit is a 91½ in. diameter contrarotating fan, driven by six Rotax turbine starter units, giving a thrust of 6,600 lb. (T/W 1.2). These are supplied with air at 160 p.s.i. from storage bottles at 3000 p.s.i.; the units include combustion chambers in which the air is heated to 1000°K. The 4-stage water cooled air compressor is driven by the road engine; it can be used while the vehicle is on the move and takes 21 or 42 h.p. depending upon the gear ratio used. With the air capacity available it can do two jumps (over a 10 ft. x 30 ft. obstacle) and then requires 7 minutes minimum to recharge for the next jump.

Propulsion is by take off on the move and/or by vehicle tilt. Stability and control is by puff pipes at the corners of the vehicle fed from the lift fan. Vertical flight path control is programmed, probably with selection of height. Thrust alteration may be by speed change or pitch change: the latter is preferable for response but not for complication. A simple auto-stabilisation system (in keeping with limited flight time) can be used, controlling the nozzle inlets. Drivers control is through the autostabilizer.

The gross weight is 5550 lb., including 1000 lb. payload, 200 lb. of airborne fuel and 120 lb. of usable air. The machine can then do 50 jumps. By using both air bottles to give 20 secs. flight, and tilting the machine, a long jump of 750 ft. should be possible.

River crossing is by swimming; a possible hovercraft modification, with an inflatable skirt, is suggested.

Comments

This system has two advantages; fairly low cost (depending mainly on cost of developed Rotax units), and instantaneous jump readiness, when once the air bottles are charged.

Against this, it cannot fly 1000 ft. though it is claimed that a long jump of 750 ft. may be achieved in development. This implies a jump from a running start at fairly high speed which might be possible from level ground, but any disturbance at take off would be as serious as a side gust.

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The control forces required are seriously underestimated, in the gust cases; stabilisation does not seem to have been studied in detail.

2.10 Westland No.2 (Jumping vehicle, with kinetic energy storage in fan)

This machine has been proposed by the firm as being more in keeping with the spirit of the specification than the helicopter solution. It is a cross-country vehicle, with a central ducted fan having heavy variable pitch contrarotating blades, which can be spun up to speed in about one minute by the road engine. The energy thus stored is released by pitch change to give a leap of 5 seconds duration.

The light-alloy semi-monocoque platform chassis carries the fan duct, cab and engine compartment. The running gear is basically similar to that of the Champ, with modified oleo shock absorber units. The road engine is a Coventry Climax V8 4 litre unit, developing 300 b.h.p. for spinning the fan but limited to 100 b.h.p. for road use. Transmission is orthodox, but includes a gearbox for selection of power to fan or road wheels.

The contrarotating fan has a diameter of $7\frac{1}{2}$ ft.; each of the 8 blades (4 per fan) weighs about 100 lb. The total energy stored in the fan is about 8 million ft. lb.; and about half of this is to be released in 5 seconds giving about 1500 mean h.p. at the fan. The fan can produce a T/W ratio of 1.8 initially (over 12,000 lb.) but collective pitch is programmed to give an appropriate thrust-time relationship, finishing with a steady descent at 6 f.p.s. The driver can control the flare-out to cope with unexpected landing conditions or to achieve a softer landing. The road engine continues to deliver its power (at full throttle) to the fan throughout. Except that the driver has limited authority in the flare out, the blade pitch programme is automatic.

Propulsive thrust is by duct inclination (8^{0}) and vehicle tilt. Control of vehicle pitch and roll is by control fans or by pressure jets at the corners of the vehicles, the latter to be fed from a compressed air supply allowing two jumps; the reservoir can be recharged in 10 mins. Control of yaw is by differential collective pitch (and hence torque) on the fans. Separate flight control column and collective pitch lever are fitted.

Stabilisation is only touched upon. It is assumed that in a 5 second leap, with programmed fan blade pitch and vehicle attitude, to give a preset jump profile, stabilisation is not required. The driver has limited authority to allow minor adjustments, particularly in the touch down.

The gross weight of the vehicle is 6750 lb. including a payload of 993 lb. and flight fuel of 180 lb. (interchangeable with road fuel - 170 lb.)

The number of jumps is 50, with a road range of 200 miles, but can be exchanged at the rate of 1 jump for 4 miles of road range.

River crossing is by swimming, with a jump out if necessary. There is a possibility of ground effect performance as a plenum chamber machine, with a hover height of one inch.

Comment

This is probably the cheapest solution of all, in terms of fan-driving complexity; it is not the lightest, because the kinetic energy storage leads to a high fan weight. Against this, the jump capability is the most limited, the maximum "flight" being about 80 ft. At full weight, the 10 ft. x 30 ft. obstacle cannot quite be jumped. Thus the jump capability of the machine depends largely on the skill of the driver (jockey ?) at take off, with some possibility of adjustment of the landing.

/The

The 5-second time of flight is not short enough to avoid the necessity for autostabilisation. The control forces required are not dealt with in the brochure but, as with the other machines, they must be large and may require considerably greater air supplies than are suggested and more complicated means of control.

The run-up time of over one minute is not particularly short, though a second jump could be made in half a minute because the fan is still rotating with about half its total kinetic energy at the end of a jump. If the fan could be kept rotating at full speed in difficult country, it would be an obvious tactical advantage (though with a tip speed of 1000 f.p.s. on contra-rotating fans it would presumably be extremely noisy*, even at zero pitch angle). According to the firms figures, this would be possible by utilising about 160 b.h.p. of the engine to drive the fan in addition to the 100 b.h.p. available for road use. Fuel consumption would of course fall to 3 m.p.g. or so. Jumping from a flying start is a possibility from level ground, but disturbance at take off might lead to stability problems as severe as from a strong sidegust.

Mean jet velocity is about 220 f.p.s. at lift-off, from the ground erosion point of view this may be reasonable. The high tip speed at maximum lift, however, will be likely to lead to noise that is some 5 - 6 db above the other ducted fans and so is audible to the same level at twice the distance.

The river crossing capability with one inch hover height in a 10 inch cavity does not seem attractive; nor would this hover height be of much value in minefield crossing.

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* Noisy in the machine; outside, at zero pitch angle most of the noise would be on the duct axis and so would not be heard on the ground.

DATA SHEET - VICKERS-ARMSTRONGS (SOUTH MARSTON) AND ENGLISH ELECTRIC AVIATION PROPOSAL

Members of the British Aircraft Corporation

(Information derived from firm's brochure)

1. General

	Scheme 'A'	Scheme 'B'
All Up Weight:	6100 lb.	8250 lb.
Payload:	970 lb.	970 lb.
Dimensions:		
Length:	19'	20'
Width:	8'-6"	9'-6"
Height:	6'-8"	6'-8"
Departure Angle:	30°	
Approach Angle:	27.5°	

Air Portability: AW.660

2. Airborne Particulars (Scheme A only)

Lift: 4 Ducted fans 45" diameter driven by cross-coupled twin engines.

Power Plant: 2 x D.H. Gnome 1350 s.h.p.

Vertical Efflux (each fan):

Quantity:	223 lb/sec.
Temperature:	Ambient
Velocity:	300 f.p.s.
Thrust:	8250 @ 3000 ft. + I.S.A. +25°
Fan tip speed:	950 f.p.s.

Disc Loading: 183 lb/sq.ft. at A.U.W.

Fuel Capacity: 145 galls.

Flight Capacity: 20.3 miles continuous flight

Stabilisation: Rolling and pitching can be controlled by differential movement of control fan blades. Forward motion obtained by tilting whole vehicle.

Time to Prepare for Take-Off: 90 secs.

3. Groundborne Particulars

Road Engine: Coventry Climax F.W.B. 2.2 Litre 6 cly. in line Max. power 135 B.H.P.

Transmission: Similar to that of Ferret with 4 wheel drive.

Suspension: Total wheel movement of 18". The sprung oleo strut effectively acting as the king pin.

Tyre Size: 9.00" x 16"

VICKERS ARMSTRONGS PROPOSAL

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DATA SHEET - FOLLAND AIRCRAFT PROPOSAL

A Member of the Hawker Siddeley Group

(Information derived from firm's brochure)

1. General

All Up Weight:	5550 lb.	Experimental vehicle only
Payload:		
Dimensions:		
Length:	16'-2"	
Width:	9'-2"	
Height:	5'-8"	
Departure Angle:	55°	
Approach Angle:	24°	

Air Portability: Beverley

2. Airborne Particulars

Lift: 7'-7½" diameter fan driven by 6 fuel/air starters powered by stored air. Air bottles charged by 4 stage water cooled compressor delivering 0.15 lb/sec. at 3000 p.s.i. @ 4500 R.P.M. The total storage capacity is 12 cu.ft.

Fuel: 25 gallons for 'hopping'.

Vertical Efflux Velocity: 274 f.p.s.

Fan Tip Speed: 640 f.p.s.

Flight Capability: 2 x 10 sec. flight, distance depends on forward speed.

Total lift: 6600 lb.

Fuel Consumption: ½ gallon/Hop

Disc loading: 124 lb/sq.ft. at A.U.W.

Stabilisation: Automatic correction for variation in vehicle weight.

Time to prepare for Take-Off: This is the time to accelerate the fan - 1.9 secs.

3. Groundborne Particulars

Road Engine: 2½ litre Coventry Climax developing 94 B.H.P. @ 4500 R.P.M.

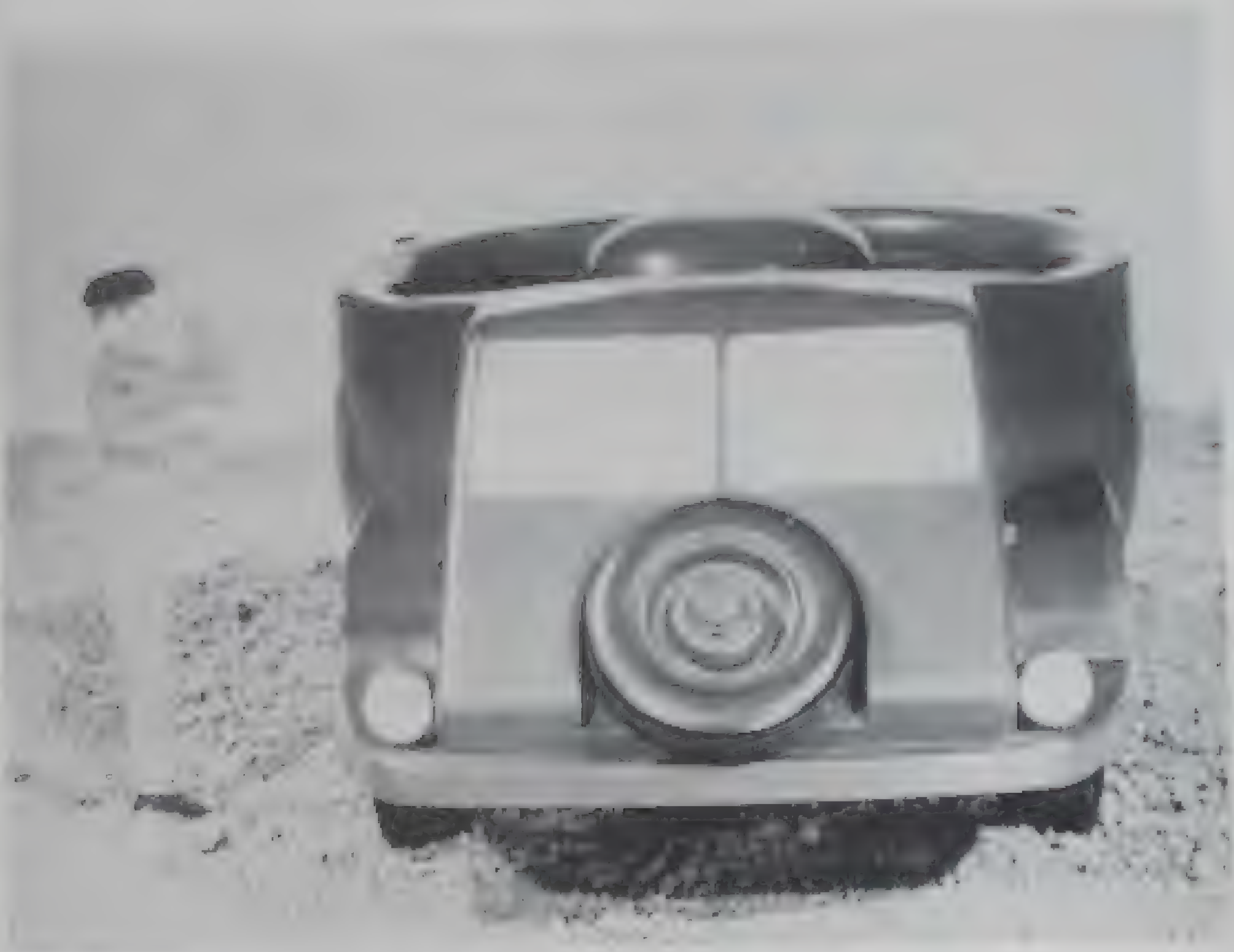
Transmission: 5 Forward speeds and reverse. 2 Speed box for compressor.

Suspension: ±6" from static. All independent using wishbones, 4 wheel drive.

Tyre Size: 7.50 x 16

[illegible]

FOLLAND PROPOSAL



46180/15

DATA SHEET - WESTLAND AIRCRAFT PROPOSAL No.1

(Information derived from firm's brochure)

1. General

All Up Weight:	7000 lb.	
Payload:	1000 lb.	
Dimensions:	Ground	Air
Length:	23'-3"	40'-0"
Width:	7'-0"	32'-3"
Height:	8'-10"	8'-10"
Departure Angle:	30°	
Approach Angle:	50°	

Air Portability: Beverley only.
AW.660 if rotor head and tail cone dismantled

2. Airborne Particulars

Lift: 4 Blade, 32'-3" dia. rotor driven by D.H. Gnome or Blackburn A129 engine. D.H. Gnome 1400 - 1550 Shaft H.P.

Vertical Efflux:
Quantity (lb/sec)
Velocity (ft/sec)
Thrust (lb)

Disc Loading: 8.5 lb/sq.ft. at A.U.W.

Flight Capability: Continuous

Fuel: 68 galls.

Stabilisation: Stable System

Time to Prepare for Take-Off: Expected to be within $1\frac{1}{2}$ minutes to convert from ground to airborne configuration. Folding to be partially by hand.

3. Groundborne Particulars

Road Engine: 106 B.H.P. Coventry Climax V-8 engine. 1.6 litre capacity. Peak output at 6000 r.p.m. using high grade motor spirit.

Transmission: Based on FV.1800. Five gear ratios, forward and reverse. Four wheel drive.

Suspension: Based on FV.1800. Independant wishbones and torsion bars.

Tyre Size: 7.50" x 16" heavy duty.

WESTLAND PROPOSAL NO.1

46180/18

46180/17

DATA SHEET - WESTLAND AIRCRAFT PROPOSAL No.2

(Information derived from firm's brochure)

1. General

All Up Weight: 6750 lb.
Payload: 823 lb.
Dimensions:
Length: 17'-0"
Width: 8'-9"
Height: 6'-3"
Departure Angle: 24°
Approach Angle: 22°

Air Portability: Beverley

2. Airborne Particulars

Lift Engine: One Coventry Climax V-8 (4 litre) piston engine rated at 300 B.H.P. (max) driving 7'-6" dia. contra-rotating ballasted 4 Blade fans. Stored Kinetic Energy principle.

Fuel: 56 gallons of 80/87 Octane Petrol (Also for ground propulsion).

Vertical Efflux:
Quantity:
Velocity:
Thrust:

Disc Loading: 153 lb/ft^2 at A.U.W.

Flight Capability: Fuel for 50 hops and 200 miles road range. Common fuel supply means interrelated hop and road range performance. Five minutes ground running between hops. Can jump from wading condition.

Stabilisation: Automatic programme for jumps, pilot has limited authority controls.

Time to Prepare for Take-Off: 80 secs.

3. Groundborne Particulars:

Road Engine: The Coventry Climax lift engine is also used for ground propulsion but with throttle restriction to 90 B.H.P.

Transmission: Fluid flywheels and 5 speed pre-selector gearbox. This unit drives the rear road wheels via the central fan/road selection gearbox and the rear differential. Four wheel drive capability.

Suspension: Based on FV.1801. Independant wishbones and torsion bars.

Tyre Size: 7.50" x 16"

WESTLAND PROPOSAL NO. 2

46180/23

46180/22

SECRET

DATA SHEET - BOULTON PAUL AIRCRAFT PROPOSAL

(Information derived from firm's brochure)

1. General

All Up Weight:	8313 lb.
Payload:	1000 lb.
Dimensions:	
Length:	16'-0"
Width:	7'-4"
Height:	6'-0"
Departure Angle:	23.5°
Approach Angle:	25°

Air Portability: AW.660

2. Airborne Particulars

Lift: Fan lift engine, Bristol Siddeley BS.59/12.

Vertical Efflux:	Cold	Hot	Stabilising
Quantity:			
Temperature:			
Velocity:	Average 524 f.p.s.		
Thrust:			
Total Thrust:	10,000 lb.		

The extent of mixing is not known.

Disc Loading: 504 lb/sq.ft. at A.U.W.

Fuel Capacity: 250 galls.

Flight Capability: 43 sorties of 1000'.

Stabilisation: Hydro-mechanical system using the lift engine gyrocouples resulting from pitch and roll disturbances.
Forward motion created by tilting the vehicle.

3. Groundborne Particulars

Road Engine: Coventry Climax F.W.B. 4 cylinder developing 100 B.H.P.

Transmission: 4 wheel drive using hydrostatic transmission.

Suspension: Swinging link system using an air spring of the Dunlop 'Bellows' type in parallel with a hydraulic damper jack.

Tyre Size: 9.25" x 16"

SECRET

When marking up documents for copying please tick the appropriate box.

SECRET

BOULTON PAUL PROPOSAL

46180/12

180/12

180/13

DATA SHEET - SHORT BROS. AND HARLAND PROPOSAL

(Information derived from firm's brochure)

1. General

All Up Weight: 7050 lb.
Payload: 823 lb.
Dimensions:

	Ground	Air
Length:	14'-1"	18'-8"
Width:	6'-9½"	9'-8"
Height:	6'-8½"	6'-8½"

Departure Angle: 40°
Approach Angle: 32°

Air Portability: Beverley or Aft-section of AW.660

2. Airborne Particulars

Lift Engine: 1 Bristol Siddeley B.S.59/11 of 8324 lb. thrust

Vertical Efflux:	Cold	Hot	Stabilising
Quantity (lb/sec)	204.92	74.39	16.69
Temp. (°K) (Entry)	Ambient + 30	1004.89	516.7
Velocity (ft/sec)	701.4	1309.3	1363.9
Thrust (lb)	4378	2966	980

Total Thrust = 8324 lb.
Effect of mixing is not known

Disc Loading: 560 lb/sq.ft. at A.U.W.

Flight Capability: Max. continuous flight 18.9 nautical miles. 38 hops of 1000 ft. without refuelling.

Fuel: 1400 lb = 175 gallons

Stabilisation: Multi-channel auto-stabilisation system, based on S.C.I. experience.
Forward accelerating thrust is obtained due to 5' basic tilt of engine and attitude change of vehicle.
Small solid fuel rockets as emergency air brakes.

Time to Prepare for Take-Off:

3. Groundborne Particulars

Road Engine: 90 B.H.P. Porsche flat four air cooled unit. 1.582 litre swept volume. Peak output at 5,500 R.P.M.

Transmission: Four speed and reverse gearbox with an auxiliary box providing two step down speeds of ratios 2:1 and 3.6:1 (2:1 for road work, 3.6:1 for cross country).

Suspension: Independant swinging arms with oleo pneumatic shock absorber units.
Wheel movement 12", Static to bump 4½", Static to rebound 7½".

Tyre Size: 7.50" x 16".

SHORT BROS. AND HARLAND PROPOSAL

46180/3

46180/4

DATA SHEET - BRISTOL SIDDELEY PROPOSAL

(Information derived from firm's brochure)

1. General

All Up Weight:	6000 lb.
Payload:	450 lb.
Dimensions:	
Length:	15'-1"
Width:	7'-4"
Height:	6'-10"
Departure Angle:	40°
Approach Angle:	40°

Air Portability: AW.660 - vehicle pulled down to 6'-5".

2. Airborne Particulars

Lift: 6'-4" diameter fan.

Power Plant: 3 Gnome engines developing 1000 h.p. or
3 A.129 Blackburn developing 1000 h.p.

Vertical Efflux:

Quantity:	680 lb/sec.
Temperature:	About Ambient
Velocity:	275 f.p.s.
Main Thrust:	5800 lb.
Stabilising Thrust:	200 lb.
Total Thrust:	6000 lb.

Disc Loading: 192 lb/sq.ft. at A.U.W.

Fuel Capacity: 175 galls.

Flight Capability: 1 hour continuous

Stabilisation: Limited authority automatic control. Forward motion of vehicle obtained by built-in tilt of fan, attitude of vehicle and control vanes.

3. Groundborne Particulars

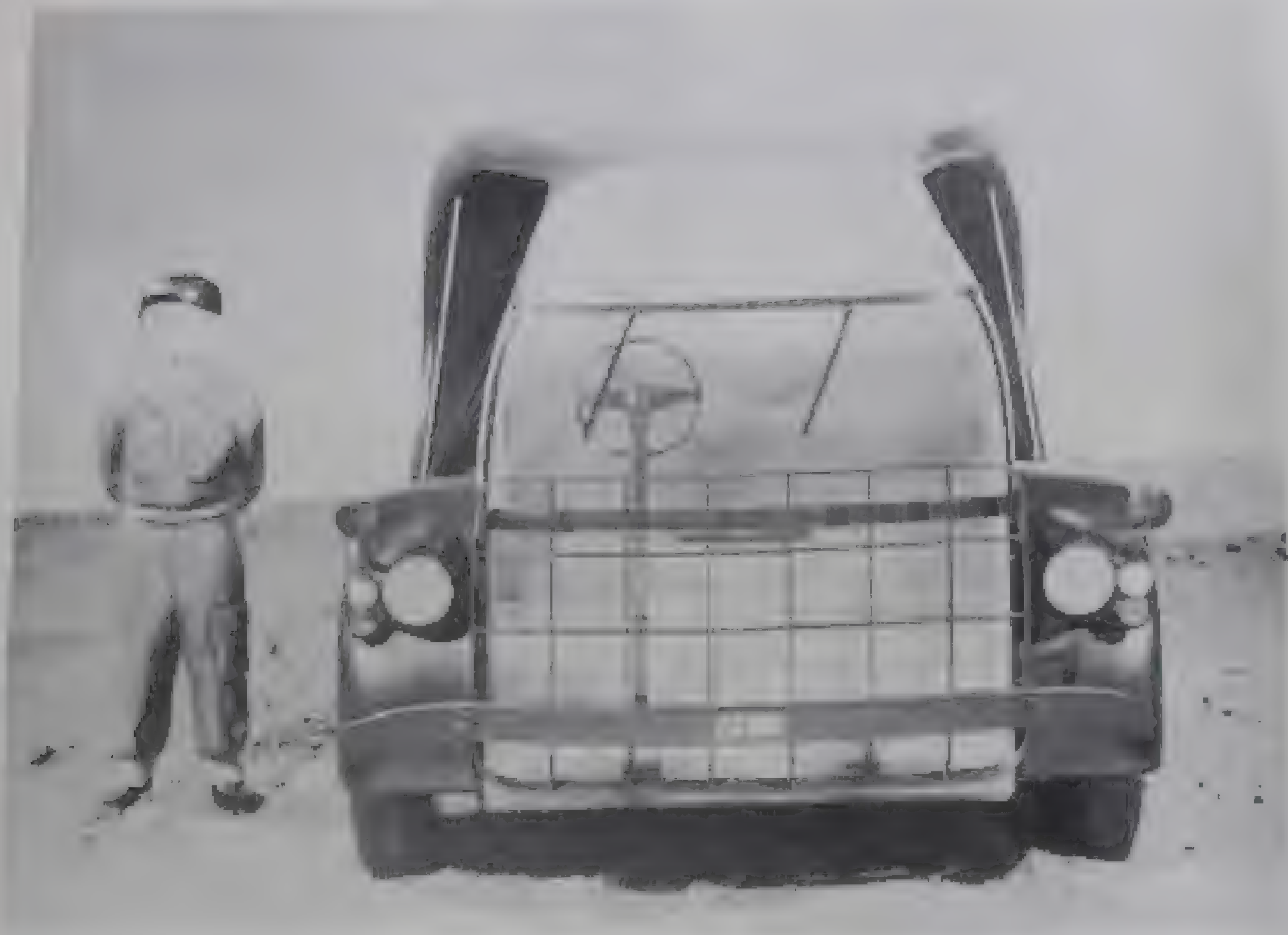
Road Engine: Rover Gas Turbine developing 140 H.P.

Transmission: Epicyclic two speed and reverse gearbox with mechanical drive to all 4 wheels.
Max. T.E. 1700 lb.
Top Speed 65 m.p.h.

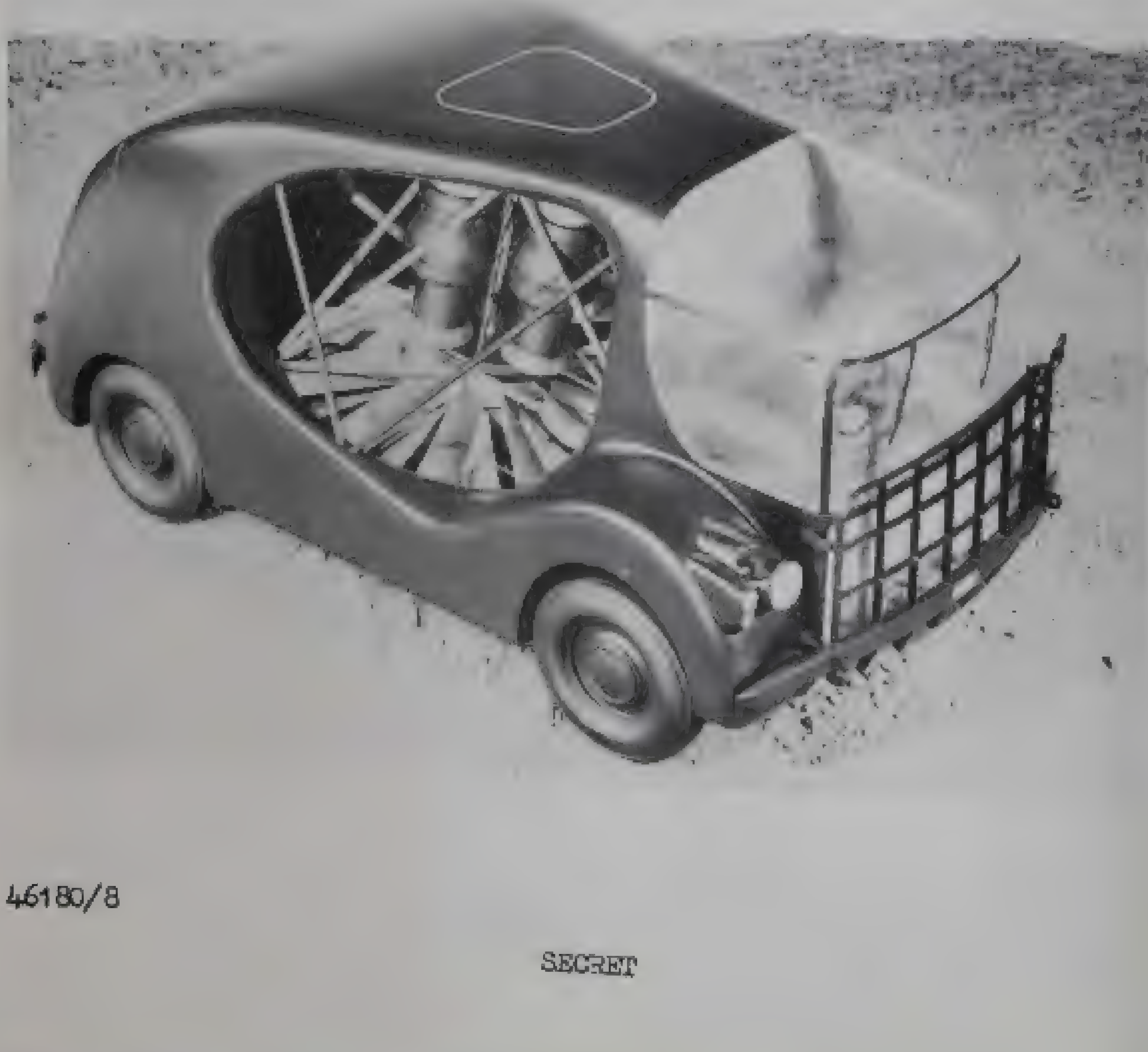
Suspension: Standard I.F.S. with De Dion type rear suspension, inboard disc brakes.

Tyre Size: Up to 7.50" x 16"

BRISTOL SIDDELEY PROPOSAL



46180/9



46180/8

DATA SHEET - HANDLEY PAGE PROPOSAL - ORIGINAL TYPE 'A'

(Information derived from firm's brochure)

1. General

All Up Weight:	8000 lb.	
Payload:	1000 lb.	
Dimensions:	Ground	Air
Length:	20'-3"	20'-3"
Width:	6'-10"	12'-0"
Height:	7'-9"	7'-9"
Departure Angle:	29°	
Approach Angle:	36°	

Air Portability: Beverley

2. Airborne Particulars

Lift: A single Rolls-Royce fan lift engine.

Vertical Efflux:
- Quantity:
- Temperature:
- Velocity:
- Thrust:
- Total Thrust: 11,000 lb.

Estimated Disc Loading: 728 lb/sq.ft. at A.U.W.

Fuel Capacity: 210 galls.

Flight Capability: 48 x 1000' sorties at sea level +60°F

Stabilisation: A limited authority automatic stabiliser, controlling the motion of puff pipes. Forward motion obtained by rotating lower part of fan ducting.

3. Groundborne Particulars

Road Engine: 2½ litre, 6 cylinder, Coventry Climax developing 100 B.H.P. at 4,700 R.P.M.

Transmission: 5 forward and reverse gears hydraulically operated. 4 wheel drive.

Suspension: Independently sprung front and rear wheels with air/hydraulic shock absorbers. 12" wheel travel, 4½" to bump stop from static.

Tyre Size: 9.00 x 16

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HANDLEY PAGE PROPOSAL

(Original Type B)

46180/6

DATA SHEET - HANDLEY PAGE PROPOSAL - SUPPLEMENT TYPE 'A'

(Information derived from firm's brochure)

1. General

All Up Weight:	10,000 lb.	
Payload:	1,000 lb.	
Dimensions:	Ground	Air
Length:	23'-0"	23'-0"
Width:	9'-0"	11'-9"
Height:	8'-2"	8'-2"
Departure Angle:	43°	
Approach Angle:	24°	

Air Portability: Beverley

2. Airborne Particulars

Lift: A single Bristol Siddeley B.S.53/5 ducted fan lift/thrust engine.

Vertical Efflux:
- Quantity: 370 lb/sec
- Temperature:
- Velocity:
- Thrust:
- Total Thrust: 15,300 lb.

Estimated Disc Loading: 1250 lb/sq.ft. at A.U.W.

Fuel Capacity: 290 galls.

Flight Capability: 80 miles continuous at 200 m.p.h. restricted to 60 m.p.h. without tail unit.

Stabilisation: Fully automatic
Forward motion obtained by rotating the ends of all four nozzles.

3. Groundborne Particulars

Road Engine: 2½ litre, 6 cylinder, Coventry Climax, developing 100 B.H.P. @ 4,700 r.p.m.

Transmission: 5 Forward and reverse gears, hydraulically operated. 4 wheel drive.

Suspension: Independently sprung front and rear wheels with air/hydraulic shock absorbers. 12" wheel travel with 4½" travel from static to bump stop.

Tyre Size: 9.00 x 16

DATA SHEET - HANDLEY PAGE PROPOSAL - SUPPLEMENT TYPE 'B'

(Information derived from firm's brochure)

1. General

All Up Weight:	10,000 lb.	
Payload:	1,000 lb.	
Dimensions:	Ground	Air
Length:	27'-6"	26'-9"
Width:	9'-0"	27'-0"
Height:	8'-2"	11'-1"
Departure Angle:	33°	
Approach Angle:	25°	

Air Portability Beverley

2. Airborne Particulars

Lift: A single Bristol Siddeley B.S.53/5 ducted fan lift/thrust engine.

Vertical Efflux:
- Quantity: 370 lb/sec.
- Temperature:
- Velocity:
- Thrust:
- Total Thrust: 15,300 lb.

Disc Loading: 1250 lb/sq.ft. at A.U.W.

Fuel Capacity: 225 galls.

Flight Capability: 45 Sorties of 1000' length
or 212 miles continuous
or 322 miles with overload fuel

Stabilisation: Simple limited authority stabiliser

3. Groundborne Particulars

Road Engine: 2½ litre, 6 cylinder, Coventry Climax developing 100 B.H.P.

Transmission: 5 forward and reverse gears, hydraulically operated, 4 wheel drive.

Suspension: Independently sprung front and rear wheels with air/hydraulic shock absorbers. 12" total wheel travel with 4½" travel from static to bump stop.

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(8)

Telex No. 2-2241
Telegrams: Avmin-London-Telex
Telephone:
Extn. 945

Any communication on the subject of this letter should be addressed to:—
THE SECRETARY
and the following reference quoted:—
BC/257/01

MINISTRY OF AVIATION

A.D./A.P.S.(Plans)
Room 518,
St. Giles Court,
London, W.C.2.

~~30~~ 16 December, 1960

D. Cardwell Esq.,
Research Division,
F.V.R.D.E.,
Chobham Lane,
Chertsey, Surrey.

Dear Cardwell,

Attached are the comments on the feasibility studies submitted against F.V.R.D.E. Specification 9258, dealing with production aspects and costs.

As agreed, we have concentrated our effort on the four basic concepts, but I am quite willing to extend the exercise and examine the designs submitted by English Electric/Vickers; Boulton & Paul and Handley Page, should you so desire.

I have already mentioned to you that we have managed to get some off-the-record cost estimates from the firms which we visited and I promised to send these to you under separate cover; together with some pertinent comments.

I have refrained from selecting the "most suitable" submission from the production point of view because of the

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(ii) Road Transmission and Suspension, Wheels, Tyres etc.

The majority of designs envisaged standard ... champ, Landrover or Ferret ...

overriding design considerations, but there will obviously come a stage when industrial aspects such as the size of the firms, equipment, labour availability and future loading will have to be examined.

Yours sincerely,

S. Newtall.

Copies to:

D.G.A.P.
D.F.S.
D.A.P.
D.E.P.
A.S./Air B.3
A.S./Air B.2

8A

Ref. PC/237/01

CRITICAL PRODUCTION COMMENTS ON THE FEASIBILITY STUDIES FOR PROJECT "PRODIGAL"

(submitted on behlaf of D.G.A.P., Ministry of Aviation)

Introduction

We have studied the brochures submitted by Boulton Paul Aircraft Ltd., Bristol Siddeley Engines Ltd., British Aircraft Corporation Ltd., Folland Aircraft Ltd., Handley Page Ltd., Short Brothers and Harland Ltd. and Westland Aircraft Ltd. In agreement with F.V.R.D.E. we have concentrated studies on the four basic design concepts put forward by Bristol Siddeley, Folland Aircraft, Shorts, and Westlands and discussed these in some detail with the firms.

2. The main object of the exercise was to establish criteria by which relative producability and cost could be assessed. It will be readily appreciated that any production assessment at such an early stage is bound to be rather vague, particularly as the vehicle is of a complex design with a great number of unknowns which can only be solved during the course of development of the project. Thus the design studies submitted vary considerably in their interpretation of F.V.R.D.E. Spec. 9258 which renders fair comparison extremely difficult and it would be unfair to favour a design study which appears to be unduly simple and cheap, because it under-rates the problems involved (e.g. control and stabilisation aspects) and penalise a more sophisticated, but realistic, approach.

3. The attached summary at Appendix "A" reviews the significant design features of the studies and Appendix "B" attempts to show a cost estimate assuming production quantities of 10, 50 and 100 based on the firm's feasibility study,

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There is no doubt that the structural design will have to be based on aircraft techniques if optimum strength/weight ratios are to be maintained with their critical impact on performance. Certain structures are complex because of the peculiar shape of the propulsion ducts, ducting, puff-pipes etc. and extensive areas of double curvature requiring accurate jigs and tools. The use of fibreglass enveloped shells (Bristol-Siddeley Engines) eases such problems, but tools suitable for Hufford stretchers will be required for any entry and exit areas of propulsion ducting if conventional materials and skin/stringer construction are employed.

(ii) Road Transmission and Suspension, Wheels, Tyres etc.

The majority of designs envisaged standard or adapted components of the Champ, Landrover or Ferret. Transmission to the road wheels is complicated by the large duct aperture on the fan lift designs, and large numbers of drive shafts and universal joints are employed. Hydrostatic transmission would certainly simplify the design, but would inevitably be more expensive, with a cost ratio of about 2:1 on a £/lb. basis.

an adjusted cost allowing for some differentials in the interpretation of the requirements, as well as a producability rating; the latter must, of necessity be of an arbitrary nature.

4. The cost estimates take account of airframe, aero-engine, accessory and equipment cost data related to representative aircraft stores, and we have also consulted D.F.V.P. on the appropriate road parts of the vehicle. The cost shown in Appendix "B" exclude all elements of research and development costs and their possible amortisation over production quantities, but an attempt was made to assess the tooling costs and these are included in the detailed project reviews.

SUMMARY

A - Cost and Production Aspects

It will be seen from Appendix "B" that the range of production costs for a quantity of 100 vehicles extends from £50,000 to £74,000 per vehicle and after discussion with some firms we are reasonably confident that the figures are within "planning" limits, bearing in mind the present stage of the art. All costs assume that production takes place within the confines of the aircraft industry except for the purchase of the road engine, transmission parts and instrument/stabilisation/control components. It can be argued that by transferring the production task to firms traditionally linked with D.G.F.V. products, this would reduce the cost appreciably, but we consider such a saving only marginal and accompanied by a number of disadvantages. In the case of airborne propulsion plant and specialist equipment we are tied to a fixed supply pattern and Prodigal costs would benefit from the larger production volume of products which are already in full production for the Ministry of Aviation (e.g. Nimbus, Gnome, Rover turbine, Rotax engine starters). The actual construction of the vehicle, assembling and testing would attract hourly rates of 25s. to 30s. compared with a rate of 15s./hour for conventional heavy motor transport bodies. The complexibility of Prodigal and the extensive functional testing required will demand higher hourly rates than those experienced on present-day transport and there should be little difference in a competitive environment. The importance of manufacture of the vehicle taking place under the same Company as the development is considerable, because of the continuous back-feed of information and experience gained in the production stage, particularly in the complex testing procedure.

B - Technical Aspects and their effects on Production Costs

(i) Structure (Hull)

There is no doubt that the structural design will have to be based on aircraft techniques if optimum strength/weight ratios are to be maintained with their critical impact on performance. Certain structures are complex because of the peculiar shape of the propulsion ducts, ducting, puff-pipes etc. and extensive areas of double curvature requiring accurate jigs and tools. The use of fibreglass enveloped shells (Bristol-Siddeley Engines) eases such problems, but tools suitable for Hufford stretchers will be required for any entry and exit areas of propulsion ducting if conventional materials and skin/stringer construction are employed.

(ii) Road Transmission and Suspension, Wheels, Tyres etc.

The majority of designs envisaged standard or adapted components of the Champ, Landrover or Ferret. Transmission to the road wheels is complicated by the large duct aperture on the fan lift designs, and large numbers of drive shafts and universal joints are employed. Hydrostatic transmission would certainly simplify the design, but would inevitably be more expensive, with a cost ratio of about 2:1 on a £/lb. basis.

(iii) Road Engines

There are obvious advantages in selecting a standard British engine and Coventry Climax appear to be catering for a comprehensive range. The Porsche air cooled engine and gear box has only a marginal advantage and is certainly more costly, whilst the use of a Rover gas turbine is not justified and would be very expensive.

(iv) Airborne Propulsion Systems

Cost and complexity-wise this system accounts for a substantial part of the total cost. The introduction of a new engine design can only be justified if no alternative means are available, quite apart from the time delay, as it would take

some 3½ to 4 years to get the new engine into the air. Although modifications may be required to the Rotax starter unit, Nimbus and/or Gnome engines, these are not of a major nature. It is also noteworthy that Bristol Siddeley's submission envisages engines which are readily available, in preference to their own products, as they are fully aware of the time lag and cost penalty of a new engine design. Engine driven fans are of a great variety, being mainly contra-rotating, but varying considerably in diameter, number of blades, rotation speed and aerodynamic form, and are also made from such widely different materials as steel, light alloy and fibreglass. Two designs also specify variable pitch control with its associated complications.

(v) Stability/Control

The designs submitted fall into the two major divisions, of those which have jump capability and those having sustained flight characteristics. There appears to be considerable doubt in the minds of the designers whether a jump capability requires a similar degree of stabilization control as the more sophisticated machines capable of sustained flight. If the project is to be regarded as a flying machine, aspects of flight safety/fail safe will add complexity and weight and only a compromise solution is feasible if the basic concept and dimensions of the vehicle are to be preserved.

COMMENTS ON VEHICLES DISCUSSED IN DETAIL

Westland Aircraft Ltd.

Proposal No. 1 (P 540-1) (Fairey design)

This design is based on the "Scout" helicopter lift system applied to a basic vehicle design to meet the requirements regarding road and cross-country performance. The hull is based upon a chassis similar to the "Champ" to which is mounted a pylon to carry the rotors. The only major departure from "Scout" practice is the hinging of the blades near the root to permit folding - a possibility already under consideration for other applications. Approximately 80% of components in the lift system are similar to the "Scout" although some transmission details may need strengthening. The lift engine proposed is the "Gnome" which is in quantity production for this type of service.

Propulsion on the ground is by Coventry Climax engine, "Champ" gearbox and transmission and wheels but with heavy duty tyres. Control in the air is by conventional helicopter methods. Cost estimates were discussed and the price of £65,000 each for a quantity of 100 off was in close agreement with Westland's estimates. As this is a type of vehicle very similar to Westlands helicopter practice, this agreement is to be expected.

Proposal No. 2 (P 540-2) (Saunders-Roe design)

This proposal is for a vehicle having very limited airborne capability, its flight being of short duration (approx. 5 seconds) e.g. clearing an obstacle 10' high by 40' long and operation in the air is relatively inflexible.

The hull comprises box members joined by diagonal bracings, all constructed in light alloy and having relatively little shaping. The fan duct is a much more complex structure and no detailed information on the method of construction or materials is available. Both light alloy and fibreglass are under consideration, but construction will involve complex double curvatures. In particular the intake lip, the geometry of which will have to be determined by tunnel testing, could be extremely complex and will need close control.

Lift is by high speed, contra-rotating variable pitch fans designed to have high inertia which are run up to speed from the road engine through a special gear box. It is proposed that the blades shall be hollow and heavy masses about which

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the blade sheath can rotate will be located at a suitable radius by means of a spider. This is necessary as a very rapid rate of response to blade change signals are envisaged to accomplish the flight pattern. To give some measure of control in yaw, it is intended that the pitch of the fans shall be differentially controlled under command. Some form of centrifugal force and weight sensitivity control will be incorporated. The manufacture of these fans with their complex hubs and hydraulic pitch adjusting mechanisms is likely to be rather expensive.

Ground propulsion is by Coventry Climax V8 4-litre engine developing approx. 300 B.H.P. and as only 100 B.H.P. will be required for road operations some form of output limiting is required. Transmission to all 4 wheels is through the special wheels/fan selector gear box and units based on "Champ" transmission. Suspension units are also based on the "Champ".

Control of attitude (pitch and roll) has not been defined. Alternatives are the use of hydraulic-motor driven fans at each corner, controlled differentially, or by reaction jets using air supplied from storage vessels, with a compressor for recharging. Stabilization is not at present considered necessary.

Components for the ground side of the vehicle will be obtained from normal supply sources and the location of production of the remainder of the components and extent of sub-contracting will depend upon group activities.

Costs were reviewed and there was considerable divergence between A.F.S. estimates and those of the firm. The A.F.S. cost of approx. £24,500 each being some 25% below that suggested by the firm. The £24,500, (derived from examination of the firms brochure) does not include any element for the control system which may ultimately be required, and it is suggested that £5,000 should be added to cover this, making a final A.F.S. estimate of £29,000 each for a quantity of 100 off.

Folland Aircraft Ltd.

This vehicle is designed for "Jump" technique having a very limited range (10' high x 30' long) when airborne.

The hull is of aircraft type construction employing light alloy material and should present no great production problems. The inside diameter of the main duct needs accurate dimensional control to maintain satisfactory tip clearances. The inner and outer panels around the ducting have double curvature profile, although the curvature in the vertical plane will be slight - Folland have all necessary equipment.

Lift is obtained from contra-rotating, fixed-pitch, light alloy fans driven by turbine units. Production of the fans should not be difficult and turbine units are based on a type now being developed for aircraft engine starting. Drive to the fans is by direct gearing on the starter shafts to teeth on the faces of the fan hubs. The turbine units are supplied with hot air obtained by burning fuel in air expanded from storage cylinders. Two cylinders are proposed - one spherical and one cylindrical, manufactured from fibreglass. So far as is known these cylinders are larger than any at present produced and development of techniques may be necessary. In view of the known temperature limitations of these materials investigations will be needed to ensure that the ambient temperatures and the final delivery temperature of the air from the compressor will not exceed material limitations. It is proposed that charging of the cylinders will be by a high-speed, light-weight, 4-stage water-cooled compressor and no such compressor is available. Follands are of the opinion that it should not be difficult to develop such equipment, but it is considered that to keep within the weight specified (130 lbs.) considerable development may be necessary. The compressor will be driven from the main engine through a two-speed gearbox.

Propulsion on the ground, with 4-wheel drive, is by a Coventry Climax $2\frac{1}{2}$ litre engine through a 5-speed gearbox and differentials, wheel and brake assemblies as employed on the Austin "Champ", all these being well-tried components, although

the latter impose a measure of weight penalty. Suspension is by independent wish-bone and long stroke coil spring dampers.

Considerable sub-contracting would be carried out, firms such as Dunlop, Rotax, Rotol have been approached regarding the compressor, Rotol and de Havilland regarding fans and vehicle components would be obtained from commercial suppliers and D.N.V. have been consulted on gearing.

Attitude whilst airborne is controlled by reaction ducts, but details are not specified. Original proposals to take air from the main duct to stabilising jets at the corners of the vehicle are now not considered to be practicable, and a separate blower system may be required. Insufficient attention has been given to stabilisation, and the development of these systems would demand a considerable effort.

Probable cost has been discussed with the firm who estimate £20,000 each for quantity production - A.P.S.(Plans) estimate based on the brochure is outlined in Appendix B and is £27,500 each for a quantity of 100 off, but even this, it is considered, will not cover the cost of auto-stabilisation equipment should this be required, and the revised price of £32,000 each is estimated.

Short Brothers & Harland Ltd.

This vehicle is designed to have prolonged flight capability and the main structure is aircraft practice employing, in the main, light alloy. Use is made of sandwich panels,- the choice between honeycomb and corrugated core has not been made, but Shorts tend to favour the latter although they have little production experience of either and some initial problems may be encountered. Most of the panels would be flat or of relatively slight curvature. As the lift engine is an integral unit, the central cylinder will not need to be held to close dimensions apart from engine pick-up points, this cylinder also acts as a closing wall for the integral tanks. Considerable attention has been given to design of the crew compartment to afford the maximum protection in the case of crash landing.

Lift is derived from a fan lift engine under investigation by Bristol-Siddeley. A family of such engines has been under consideration for some three years, but has not yet been finalised, and design and development is likely to take a number of years, and this would delay development of the vehicle.

Ground propulsion, through 4-wheel drive, is by a Porsche engine and integral gearbox and whilst this may have some advantages the choice does not seem to be an ideal one, and a British alternative would perhaps be preferable and cheaper. Transmission follows orthodox lines, although new gearboxes and differential units would need to be designed. Suspension design is based mainly on aircraft practice and is backed by considerable detailed knowledge at Shorts, although they would not necessarily produce the units which would be sub-contracted to Electro-Hydraulics or Dowty.

Control during flight is by reaction ducts at the corners of the vehicle, having controllable orifice openings at the extreme tips, the air supply being from the main lift engine. As the pipes and control mechanisms for the shutters are hinged to allow folding back when the vehicle is in use on the ground, difficulty may be experienced with the rotating joints. An advanced form of auto-stabilisation having triple-channels for pitch and roll, developed for the S.C.I. aircraft, is proposed and whilst the use of this would have considerable advantages during vehicle development it is considered that it would be too costly for inclusion in production vehicles, and a simpler system could possibly be devised.

Estimation of costs is difficult due to the lack of detailed information on the lift engine, the cost of which is likely to exceed 50% of the total cost of the vehicle, but this has been discussed with Shorts and with Bristol Siddeley Engines and a tentative figure of production costs for the engine, neglecting development charges, has been arrived at. The total cost of the vehicle, as

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indicated in Appendix B, approximates to £50,000 each for a quantity of 100 off and this is in reasonable agreement with the firm's own estimates. It is considered however, that by employing a less sophisticated form of stabilisation the price could be reduced by some £2,000 to £3,000 - giving the possible figure of £48,000 each.

Bristol Siddeley Engines Ltd.

This vehicle has many promising features and is designed to give the required ground performance whilst having full airborne capability and a considerable safety factor, in that the full flight role could be carried out with one of the three engines inoperative.

The main body of the vehicle is of fibreglass reinforced with tubular steel, a form of construction which can be relatively cheap for a small quantity, although in the present case it would seem that the designed shape would be most difficult to achieve by any other method of construction. This shape has been evolved as the result of considerable study of the airflow characteristics and of wind-tunnel testing to achieve satisfactiry conditions of fan air intake. In general, the tooling for this type of construction is cheap, but it must be pointed out that for a vehicle of this complexity considerable jigging will be necessary to ensure the accurate location of the numerous pick-ups required.

Further, development is likely to be difficult since it would be necessary to arrange for reinforcing within the fibreglass structure for any additional attachment points. The fan sub-frame in addition to being a main structural member also carried a series of vanes within the fan efflux to effect vertical and directional control. This unit is most complex since the 44 vanes proposed are grouped into four segments in order that they can be operated in unison and differentially, and considerable mechanical difficulties may be encountered in an effort to ensure satisfactory functioning of this unit with acceptable control loads. From a serviceability aspect it should be noted that this complex arrangement will be in the vicinity where mud and dirt are likely to be encountered particularly during cross-country working.

Lift is obtained from contra-rotating fixed pitch steel-bladed fans powered by three aircraft gas turbines having the normal accessories removed, each giving approximately 1,000 H.P. Production of the fans should not be difficult, but this might become complicated if Bristol Siddeley's suggestion that hot air de-icing is necessary is agreed. Alternative engines are suggested - Nimbus or Gnome - and of these the former is the cheaper being of less sophisticated design, but having less development potential. The reason for three engines is mainly to give safety in the event of the failure of one engine and it may be that performance with two engines would be considered satisfactory. The coupling of the outputs from the engines and transmission to the fans is complex and the necessary gearing is likely to prove expensive in production.

For ground propulsion a gas turbine engine is specified, this choice being based mainly on the advantage of having a common fuel and on the possibility of using air from the compressor to start main lift engines - but such an engine is costly and it might be advantageous to substitute a commercial piston engine. The use of the turbine engine would seem to necessitate completely new transmission units comprising an epicyclic gearbox, transfer box, chassis mounted front and rear differentials and step-down gear drives at each wheel with inboard disc brakes and this also would be costly. Suspension is by combined coil and airspring units based on aircraft practice.

Control during flight is by stabilising jets supplied with air from a centrifugal blower driven from the fan gearing, the ducting to the jets - which are located within the wheel arches - being moulded into the body shell. During discussion, Bristol Siddeley intimated that their original proposals may not be satisfactory and they may have to arrange for greater air supply to the jets. The blower is to be designed and developed and the complexity is such that difficulties may be met in the early stages if this is made of glass fibre as proposed. A simple form of gyro stabilisation is proposed, but details have not been worked out.

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The majority of components, apart from vehicle parts, would be manufactured by Bristol who have experience of all techniques involved. Gyro-stabilisation equipment would be sub-contracted to a specialist firm.

Cost estimates have been discussed and the A.P.S.(Plans) figure of £51,000 each based on the quantity of 100 slightly exceeds the Bristol estimate, but only marginally. As the former figure is based on a cost/weight assessment and it is thought that the system weights indicated in the brochure may in some cases be optimistic, it is felt that an addition of approximately £2,000 should be made to cover the possibility of the achieved weights being greater than the estimated figures, giving a total estimate of £53,000 each. (Nimbus engines)

Brief Comments on Vehicles not Investigated in Detail

Boulton Paul Aircraft Ltd.

The vehicle has been designed to have sustained flight characteristics, the basic structure being relatively simple and based on aircraft fuselage practice, having very simple contours. The central duct will not need close dimensional control but the intake lip may need considerable tunnel testing before final design is achieved and resulting profiles may be complex.

Lift is by BS 59/12 ducted fan lift engine similar to that already outlined in Short's proposals. Design and development of the engine would delay work on this vehicle.

After considering a number of engines on the basis of total engine +fuel weight/ 100 BHP the Coventry Climax FWB-6 cylinder engine is specified. Hydrostatic transmissions to Boulton Paul design is proposed, this having 4 wheel drive with motors mounted within the wheels. This is likely to be much more expensive than conventional transmissions. Suspension is by orthodox swing link with air suspension and hydraulic dampers.

Control during flight is by reaction jets at four corners of the vehicle, air being obtained from the main engine fan.

Estimate of cost (based on the brochure) prepared by A.P.S. (Plans) is £52,000 each for a quantity of 100 off.

English Electric Aviation (Vickers-Armstrongs Ltd.)

This vehicle is designed to have sustained flight sufficient to meet the major requirements of the specification. The hull is of semi-monocoque design similar to aircraft fuselage practice and is of light alloy. The fan ducts would involve complicated and costly sheet metal work to achieve the profiles and accuracy. Lift is by four engine-driven variable pitch fans driven from two Gnome aircraft gas turbine engines and the cross coupling of the drive shafts would require transmission similar to that employed in helicopter design. The pitch of the fans is cross-coupled for collective and differential control and the design of hub mechanisms will be complicated. A Coventry climax FWB road engine is proposed and transmission units are all similar to "Ferret".

Estimate of cost of this vehicle is £68,000 each for quantity of 100.

Handley Page

Type A

A vehicle with sustained flight capability. Hull has integrated body structure based on aircraft practice, a large number of panels having double curvature and the introduction of the partly-external station for the commander considerably complicates the structure.

/Lift

Lift is from a Rolls Royce fan lift engine not yet designed and having a controllable aspect outlet duct. Road propulsion is by Coventry Climax engine, driving all wheels through specially designed gearboxes. In order to avoid engine efflux a complicated arrangement of shafts and universal joints is specified and further complication is added by providing hydraulic jacks to raise the vehicle from the ground prior to take-off.

Control is by reaction jets from hinged puff pipes having variable orifice nozzles.

Estimated cost of the vehicle is £47,000 each for a quantity of 100 off.

Type B

Capable of sustained flight by the incorporation of hinged wings and tail unit. Hull structure basically similar to Type A with provision for mounting of an additional engine having swivelling, birfurcated ducts for vertical and horizontal thrust.

Lift is from 2 Rolls Royce lifting engines, one as Type A, the other a scaled version.

Ground propulsion is similar to Type A.

Control in flight is by normal aerodynamic surfaces, jet efflux nozzles and reaction jets from hinged puff pipes. The elaborate inter-connection of all these controls would be extremely expensive in prime cost and maintenance. Simple stabilisation is proposed.

The complexity of this machine makes it the most expensive to produce - estimated at £74,000 each for 100 off, and as it becomes a true flying machine piloting and maintenance would need to be of a high order.

NOTE:

No consideration has been given to the Mk. 2 vehicles based on the BS 53 engine, the brochure for which was received after investigations were completed.

A.P.S.(PLANS)
December, 1960.